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FOREST PLANTATION PROTECTION against DISEASES and INSECT PESTS

COMMONWEALTH AGRICULTURAL BUREAUX
10 JUL 1954

Food and Agriculture Organization of the United Nations
Rome, Italy June, 1954

SOME FAO FORESTRY STUDIES

Planning a National Forest Inventory $1.00 5s.

Forestry and Forest Products Study No. 1, by J. D. B. Harrison. September 1950, viii + 88 pp. (EFS)

Prepared for the use of administrators and advisers.

Forest Policy, Law and Administration $2.00 10s.

Forestry and Forest Products Study No. 2, by T. François. December 1950, iv + 211 pp. (EFS)

A comprehensive study designed to assist countries in formulating sound forest legislation and administration.

Grazing and Forest Economy $2.00 10s.

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This study is the combined work of the Forest Policy Branch of the Forestry Division, and deals with the problems as they affect temperate, tropical and arid regions.

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A valuable work of reference.

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Eucalypts for Planting $3.50 17s. 6d.

Forestry and Forest Products Study No. 11. 1954, 380 pp. Available in French; English edition in preparation.

The present monograph by recognized authority sums up for foresters the highlights of world experience to date with this important genus. It summarizes available material on botanical and sylvical characteristics; nursery and planting methods, and technological properties and uses.

FAO Forestry Development Paper No. 3

FOREST PLANTATION PROTECTION AGAINST DISEASES AND INSECT PESTS

In response to numerous requests, FAO is initiating a series of studies on the various phases of forest planting. Expert consultants have been engaged to prepare these studies, which will include such subjects as choice of species and sites; seed collection, treatment, and shipment; nursery, planting, and direct seeding techniques for various regions. When the series has been completed, it may be possible to assemble the several studies in a revised form in a "World Forest Planting Manual".

The present volume, the first in the series, has been prepared by J. S. Boyce, *Professor of Forest Pathology, Yale University.*

MARCEL LELOUP
Director, Forestry Division

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, Italy June, 1954

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Introduction

THE history of large-scale planting shows that the continual cultivation of any plant on monocultures over extensive areas increases the risk of disease and may even cause serious epidemics. This is true for forest trees as well as for agricultural crop plants.

In forestry, large-scale tree planting is undertaken usually for reforestation or afforestation, but occasionally it is done even though natural reproduction can be had because natural stocking may be too slow to meet the requirements of intensive management seeking the maximum financial gain. From plantations in western Europe, where planting first began as an important part of forestry practice, and also to a lesser degree from plantations in other parts of the world, much can be learned that will serve to make future planting more successful. Planted stands have proven to be particularly liable to disease, using this term in its broadest sense to include the injurious effects of insects, fungi, bacteria, viruses and other pathogens, as well as unfavorable non-infectious agencies.

General Considerations

NATURAL forest sites of good quality usually suffer comparatively minor injury from native pathogens. Although epidemics may occur which appear alarming at first they usually subside after a few years without having caused disastrous damage. Pathogenic fungi and insects are almost invariably present in all such stands without becoming unbearably destructive. Of course, if such stands are overmature, losses from decay or from tree-killing bark beetles can be extremely severe. Consequently, when damaging disease occurs in a stand, it is rarely sufficient to decide that the cause is a certain parasitic organism or a non-parasitic agent, but the reason why the organism or agent is able to cause damage is the important point to be determined. The factors to be considered are:

1. whether the tree is inside or outside its natural range either vertically (by altitudes) or horizontally (by latitude), and particularly whether it is native or exotic;
2. whether the stand is naturally or artificially regenerated;
3. whether the source of the seed is suitable, that is, whether the proper race within a species has been selected;
4. whether the stand composition is natural or has been radically altered;
5. whether the site quality is good or poor, either naturally poor or made so by man's mistreatment;
6. whether the pathogenic organism is native or introduced;
7. whether there have been any unusual climatic conditions.

SITE SELECTION

Natural stands show that the most important factor in relation to disease is tree vigor. Stands on good sites are not damaged significantly by native parasites, but those on poor sites often suffer severely. Site selection is all-important because no amount of care can save a stand in an unsuitable environment. Selection of favorable sites for deodar (*Cedrus deodara* Loud). had more effect in controlling mor-

tality from trunk rot caused by *Trametes pini* (Thore) Fr., from root rot caused by *Fomes annosus* (Fr.) Cke., and from needle rust caused by *Peridermium cedri* Barclay (Khan, 1948) than attempts to eradicate the fungi from unfavorable sites. With natural regeneration of native species the stand is adapted to the land it occupies; even so, on marginal and submarginal forest land satisfactory timber stands cannot be grown because of diseases or other factors. The maintenance of a protection forest that will supply a limited amount of wood for conversion, fuel wood, posts, and such products is all that can be expected.

It is with artificially reproduced stands, particularly planted stands, that the importance of site quality is most apparent, and there are many examples of an unsuitable environment increasing the incidence of disease (Day, 1934). The relation of disease to lack of vigor may be so constant that the attack by a pathogen can be used as a sure indicator of unfavorable growing conditions for the host, as for example dieback of twigs of planted exotic pines in New Zealand caused by *Diplodia pinea* (Desm.) Kickx. (Birch, 1936, page 18).

Thinning

Even on good sites, stands must be properly cared for, particularly planted stands. Too often plantations are established only to be neglected, so that serious losses occur. Timely thinning is essential to maintain stand vigor; if a stand stagnates it becomes susceptible to disease. In Great Britain, where most stands are planted, it has been stated that fully 75 percent of the troubles caused by fungi and insects is primarily chargeable to neglect of thinning (St. Clair-Thompson, 1928, page 157). Planted red pines (*Pinus resinosa* Sol.) in Michigan and New York were attacked by *Tympanis confusa* Nyl., causing an annual canker on the main stem because the trees were lowered in vigor by stagnation of the plantations resulting from neglect of thinning (Baxter 1937, page 31; Hansbrough, 1936, page 38).

Vigorous early growth is no assurance of satisfactory long time development. The critical period for most stands, varying with species, is from approximately 20 to 40 years of age, that is, the pole stage, when stands make the greatest demands on the site. Scotch pines (*Pinus sylvestris* L.) in Pennsylvania developed so vigorously for the first 20 years that they were comparable to the best plantations of this tree in Europe. The plantations then disintegrated so rapidly from various factors, including attacks by fungi and insects, that further planting of the tree seemed useless (Aughanbaugh, 1935).

Fire and Over-cutting

Where forest conditions have deteriorated considerably over extensive areas by fire or by destructive cutting, the new stand, particularly when young, is likely to suffer more severely from disease than usual, especially from non-infectious diseases caused by agencies such as drought, frost, winter injury, and unfavorable soil conditions. The destruction of normal forest conditions can lead to such drastic modifications in site that on less favorable locations it may be impossible to establish again for decades a satisfactory stand of the climax species, even by planting. On and around Mount Hebo in Oregon an excellent mature and overmature Douglas fir forest of over 100,000 acres was completely destroyed by fire. The burn was replanted with Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] but although the entire area had been completely covered with Douglas fir, the plantations on the exposed upper slopes and ridge tops as well as in the frost holes were unsuccessful. Not until the newly planted trees adjacent to these locations attained a sufficient height to afford protection, could a stand develop there.

Forest land can be so changed by heavy cutting followed by repeated fires that it becomes necessary to restock it first with species less exacting in their requirements, in order to restore and improve the site sufficiently so that the more valuable species can again be grown successfully. In the white pine region of the Great Lakes (U.S.A.) hundreds of thousands of acres that once had excellent stands of eastern white pine (*Pinus strobus* L.) and red pine (*P. resinosa* Sol.) can now support only jack pine (*P. banksiana* Lam.) and scrub oaks (*Quercus spp.*), much inferior species. Not until the soil is improved by the less desirable species can white and red pines be restored to their one-time natural habitat.

Regeneration

In general, naturally regenerated stands are less susceptible to disease than those artificially reproduced. Seedlings are preferable to sprouts because sprout growth is usually more susceptible to disease. In California, the powdery mildew on oak sprouts caused by *Sphaerotheca lanestris* Hark., that dwarfs them and even causes witches' broom formation, is of no consequence on seedlings. Whether stands established by direct seeding are more susceptible to disease than naturally regenerated stands is problematical, but planted stands are. At best, trees are more or less injured by planting. Roots are particu-

larly subject to injury. Root rot is more prevalent in planted than in natural stands. On the Island of Bornholm in the Baltic Sea, root rot caused by *Fomes annosus* (Fr.) Cke. was more prevalent in planted than in naturally reproduced silver fir (Boyce, 1927, page 14). *Polyporus schweinitzii*, which ordinarily decays heartwood in the butt of large conifers, has severely damaged planted eastern red and white pines in New York by killing roots (York, Wean, and Childs, 1936). This fungus also damaged a plantation of eastern white pine in Michigan, although the root rot did not appear until almost 30 years after planting (Baxter, 1937, pages 22 and 33).

Provided that plantations are established on suitable sites, of species adapted to the locality, with stock grown from seed from the proper locality and from thrifty mother trees, and, further, provided that stand composition is correct and that the stock has been properly grown in the nursery and is carefully planted, plantations should develop almost as well as naturally reproduced stands. Of course, there is weakening from the shock of planting and from the curtailed and unnaturally placed root system characteristic of planted trees. The latter handicap is never entirely overcome, and therefore planted trees are usually less disease resistant.

Pure Stands

There is always a tendency to establish pure plantations, rather than mixed, without regard to how the planted species occurs naturally, either because both silviculture and utilization are simplified in pure stands or because of the economic pressure to favor a more valuable species over its less valuable associates. Pure stands are more susceptible to diseases, particularly those caused by introduced parasites, than mixed stands. Mixtures of conifers and hardwoods are especially desirable because these two classes of trees in general have their own groups of parasites. A pure stand is ideal for a pathogen to build up to epidemic proportions. Infection is direct and rapid from tree to tree, and if the one species is destroyed nothing is left. The most hazardous are pure, even-aged stands, because parasites are often virulent during only one stage in the development of a tree. The first attempts to grow rubber trees [*Hevea brasiliensis* (Mull.) arg.] in plantations in South and Central America failed because a leaf spot fungus (*Dothidella ulei* P. Henn.), harmless on the few scattered trees per acre in the natural mixed jungle, caused repeated severe defoliation in pure planted stands.

Pure stands of trees outside their natural range are particularly liable to damage. Among the diseases known to be more prevalent in pure stands are larch canker caused by *Dasyscypha willkommii* (Hart.) Rehm (Ackers, 1925), Tympanis canker caused by *Tympanis confusa* Nyl. (Hansbrough 1936 : 20), oak mildew caused by *Microsphaera quercina* (Schw.) Burr. (Day, 1927), terminal killing of eastern white pine (*Pinus strobus* L.) by *Pissodes strobi* Peck (Boyce et al., 1932), spruce needle cast caused by *Lophodermium macrosporum* (Hart.) Rehm, pine needle cast caused by *L. pinastri* (Schrad.) Chev. (Baxter, 1933, page 24), and defoliation caused by the nun moth (*Lymantria monacha* L.). The decreased amount of larch canker in stands composed of European larch (*Larix decidua* Mill.) mixed with other species, as compared to pure stands of larch, is attributed to maintenance of better soil conditions in mixed stands so that larch there develops more vigorously (Hiley 1919, page 72) and consequently is more disease resistant. Chronic chlorosis of European larch induced by adverse soil conditions was less severe in mixed plantations of larch and Scotch pine (*Pinus sylvestris* L.) than in pure larch (Day, 1949).

The chances are strongly against the long time success of pure stands unless a species naturally forms such stands. Champion (1933) maintains that in Europe failures of pure stands cannot be ascribed to the purity of the crop but rather to mistakes in management, to planting extensive areas with a species outside its natural distribution either as regards climate or soil, to planting on soils perhaps potentially suitable but rendered unsuitable by undue exposure or other faulty treatment, to using unsuitable strains of seed or planting stock, to fungous and insect attacks, and so forth. However, the idea that purity as such is safe should be limited to species which naturally grow in pure stands. There is also much evidence that growing species in pure stands which naturally occur in mixture can ultimately lead to a serious decline in productivity resulting from the development of unsatisfactory soil conditions. This will be a slow and, for a long time, an almost imperceptible process, not culminating for several rotations or more; but once such a condition is reached, it will probably be difficult, or nearly impossible, to restore the soil to its original state. In Germany, where Norway spruce (*Picea abies* Karst.) has been established outside its range in extensive pure stands, commonly on natural hardwood land, growth was satisfactory at first, but reduction in rate of growth together with insect and fungous attacks have become so serious that special measures to maintain the productive capacity of the soil have been advocated (Wiedemann, 1924),

and conversion into mixed stands has been recommended (Hitschhold, 1934; Ostwald, 1934; Priehäusser, 1935). The preference for large, even-aged afforestation with coniferous species in Czechoslovakia has resulted in soil deterioration with severe outbreaks of pathogens and even the change from natural mixed coniferous and hardwood stands to pure Norway spruce and silver fir (*Abies alba* Mill.) has been calamitous (Papánek, 1948). The stunting of spruce and pine (*Pinus sylvestris* L.) plantations in Bohemia is attributed to the deterioration of chemical properties of the soil caused by the removal of forest litter, by clear cutting and by the use of conifer monocultures (Nêmec, 1947). The decline of pure spruce stands in Austria necessitates the reintroduction of beech (*Fagus sylvatica* L.) and silver fir (Fröhlich, 1949). From 1855 to 1875, extensive plantations of maritime pine (*Pinus pinaster* Sol.) were established in the Landes region of France and managed as pure even-aged stands without any hardwoods or undergrowth. At present, growth is declining, resin yields have decreased and natural reproduction is hard to obtain. These difficulties are charged to the accentuated development of hardpan which now characterizes 60 to 80 percent of the soil in the region (Arend, 1948).

Unfortunately, in the establishment of stands by afforestation or by reforestation with species other than those that originally occupied the area or with the same species but with stand composition greatly changed, it usually takes many years before the result can be seen. Early promise of success is no guarantee for the distant future. Since the continued productivity of a forest can be assured only if it is handled in accordance with biological laws, many stands today in those countries where forest production has been practiced for the longest time are unsuited to the sites on which they occur. Consequently, such stands require conversion either in species composition or form of management to maintain productivity in the future. For example, it is estimated that more than one-fourth of all forests in Switzerland need conversion (Leibundgut, 1947).

From the economic standpoint one species may be so much more valuable than its natural associates that it may prove to be financially sound to grow it in pure stands, although with changing demand there is no assurance that any species will retain its relative value. When pure stands are established to replace mixtures, this should be done with full understanding that additional expenditures will have to be made for protection against parasites and for silvicultural measures such as thinning and pruning. Even then the plantations may not be a success, or success in the first rotation may change to failure in

the second. In southern New England, eastern white pine (*Pinus strobus* L.) which reaches its best development in mixture with hardwoods is now growing to a considerable extent in pure stands, both planted and naturally reproduced, where it has reclaimed abandoned farm lands. However, to grow pine of quality, expenditures must be made to control the white pine weevil (*Pissodes strobi* Peck) or to repair stands already damaged (Maughan, 1930). In addition, the crop trees must be pruned (Hawley and Clapp, 1935).

Introduction of Exotic Trees

In large-scale planting programs the tendency is to establish pure plantations of exotic conifers. The need throughout the world has always been for softwoods, and North America is the only continent with sufficient volume and variety of species to fulfill all requirements. Furthermore, certain North American conifers grow so much more rapidly than conifers in other parts of the world that it is only natural to attempt to establish them wherever there is need for softwoods. Exotics should be introduced only if they fulfill some definite need not met by native species. Many years are required to learn enough about an exotic to determine whether or not it can be successfully established and perpetuated. First, there is the problem of securing seed of correct provenance; second, the difficulty of proper site selection; third, the question of whether an exotic will be silviculturally and commercially desirable even on the best sites in its new home; and finally, the possibility that the foreign species may be attacked by a parasite previously of little consequence.

There are three great hazards from parasites in the use of exotics:

1. a parasite of minor significance on the exotic in its native habitat may be introduced along with it and become extremely severe under the new conditions;
2. the exotic will encounter a parasite in its new environment to which it has no resistance so that the tree will be valueless;
3. a parasite of the exotic may be introduced on it which will be exceedingly destructive to a native tree.

Theoretically, by means of measurements of climate and soil it should be possible to ascertain the exact ecological habitat of any species, or of its races if the species is not racially uniform, and then to find equivalent habitats no matter how geographically remote. Actually, the time and money necessary to do this would be considered prohibitive. In addition, an introduced species is nearly always planted in pure stands, even though the tree naturally grows in mixture. A species normally growing in mixture is more or less dependent on the other species for its welfare, probably in some instances to such an

extent that it cannot succeed without them or their equivalents. Finally, it is impossible so far to evaluate pathogenic factors, which can cause the failure of an exotic even though climatic and soil factors are favorable. Consequently, the introduction of exotics continues to be based on trial and error, with a century or more of experience often needed before success or failure can be determined.

Europe

Western Europe where tree species, particularly conifers, from all over the Northern Hemisphere have been introduced, is an unsurpassed region from which to obtain information on the behavior of exotics. It is notable that after more than two centuries of experience with them, the majority of foresters in western Europe are pessimistic regarding exotics, because they have not yet found a completely successful introduced tree, even though certain species showed great initial promise.

There is, however, justification for the introduction of exotics into countries with few commercially valuable tree species. Europe, for example, has relatively few species of value; parts of it do not have one native conifer that attains timber size. Furthermore, in all of Europe there is not a single pine yelding softwood of such highly desirable quality as eastern white pine (*Pinus strobus* L.). The only white pine in Europe is Balkan pine (*P. peuce* Griseb.) which occurs limitedly in the mountains of the Balkan Peninsula, but the wood is almost as heavy as that of Scotch pine (*P. sylvestris* L.). The native European trees grow slowly, so there has been a search for faster growing species. Eastern white pine grows more rapidly than the native European conifers with which it has been associated (Badoux 1932 : 420; Ionov 1939). In northern Germany near Eberswalde, 45-years-old Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] was the same size as Scotch pine 100 years old. Near Tharandt, Douglas fir trees 55 years old were from 14 to 20 inches in diameter at breast height, just twice the size of Norway spruce (*Picea abies* Karst.) of the same age mixed with them. In southern Germany, near Munich, 45-year-old Douglas fir was the same height as 77-year-old planted and naturally reproduced silver fir (*Abies alba* Mill.).

Eastern white pine

The first exotic to be extensively planted in continental Europe was eastern white pine introduced in 1705. At first of great promise and hailed with enthusiasm, it finally encountered an unpredictable

pathogenic factor, white pine blister rust caused by the rust fungus, *Cronartium ribicola* Fisch., a migrant from Asia, with the result that the tree was all but abandoned throughout Europe. Of late years it is again finding some favor because in certain localities there are no or few susceptible currant and gooseberry bushes (*Ribes*), so that the tree is able to survive. Actually, where the rust fungus does not occur or where it is no more serious than a tolerable nuisance, the tree is completely fulfilling the true test of a successful exotic, which is that it maintains itself by natural reproduction in competition with the native species. The wide range of soils on which white pine will grow vigorously in Europe is impressive. Both in Upper Silesia and in Switzerland, it was seen flourishing on pure peat. Also in Switzerland there were superb mature trees which had developed in mixture with beech (*Fagus sylvatica* L.), Scotch pine and a little Norway spruce. In southern Germany the tree was seen in its fourth generation, the first two generations having been planted and the second two naturally reproduced.

Douglas fir

Following the first world war, Douglas fir found high favor and was extensively planted, although enthusiasm diminished somewhat in time because of the low quality of wood produced. The first pathogenic factor to threaten the tree was Phomopsis canker caused by a European fungus, *Phomopsis pseudotsugae* Wilson. This turned out to be not as serious as first feared, being largely connected with frost. Next was Rhabdocline needle cast caused by *Rhabdocline pseudotsugae* Sydow; the causal fungus coming from the native home of the tree but with its virulence increased apparently by the damper European climate during the growing season. Fortunately only the intermountain and Rocky mountain or blue forms of the tree were attacked, the coast or green form, the really valuable form for Europe, being unmolested. At about the same time an aphid, *Adelges cooleyi* Gill., on the coast form was causing some concern but it proved to be tolerable. Now, a severe disease, Adelopus needle cast, apparently caused by the fungus *Adelopus gäumanni* Rohde, which seems to attack all three forms of the tree, has made the future of Douglas fir in Europe dubious (Boyce, 1940).

Planting of the species has been given up in much of southern Germany, while in Switzerland it is being used in mixture only, not with

the idea that the mixed stand as such will check this disease but merely to have other species to take the place of the Douglas fir in the stand should the disease prove as catastrophical as is now feared.

Sitka spruce

Because of the difficulties besetting Douglas fir, it was natural that Sitka spruce [*Picea sitchensis* (Bong.) *Carr.*] should increase in favor, so that by 1935 it was thought that this species might supplant Douglas fir for extensive planting. However, in 1939, in Holland, was seen the last of what had been a fine 40-year-old stand. In 1935, when the stand comprised nearly 300 trees per acre, a few began to die from attack by a bark beetle, *Dendroctonus micans* Kugel., which soon reached epidemic proportions so that by 1939 only 30 trees per acre remained. These were clear cut within a few years. Similar beetle attack has occurred elsewhere so it now seems doubtful that Sitka spruce can be grown to a greater age than 40 to 50 years in western Europe. *D. micans* occurs naturally on Norway spruce (*Picea abies* Karst.) but causes little damage.

Sitka spruce is also vigorously attacked by a louse or aphid, *Elatobium* (*Aphis*) *abietinum*, that causes considerable defoliation in some plantations but how serious this may be cannot be predicted as yet.

Sitka spruce plantations that have failed at 20 to 45 years old with no pathogen responsible have been seen in Germany, Switzerland and Great Britain. These failures seemed clearly to result from an unsatisfactory site. Sitka spruce is exacting in its site requirements, but too often it has been planted on unsuitable soil, where the annual precipitation is too low, where temperatures are too severe or where some other adverse factor occurs. Unfortunately, the bad effects of an unsuitable site frequently do not appear until some years after a stand has been established, growth of the earlier years being vigorous. Sitka spruce on the whole is better adapted to Great Britain, where the climate is nearer that of its native habitat, than to most of continental Europe. Even so, care must be exercised in selecting the areas where it is to be established.

Grand fir

Grand fir (*Abies grandis* Lind.) is now being most favorably regarded by many foresters in western Europe because of its rapidity of growth and freedom from disease so far. It is thought that it may ultimately take the place it was first hoped that Douglas fir would occupy and

next to Sitka spruce, neither of which are fulfilling their original promise. For example, in Great Britain grand fir will grow more rapidly than any other conifer. However, unless the site has a mean annual precipitation of 50 inches or more, growth declines at about the age of 50 years and the trees are no longer vigorous, although so far no definite disease has developed. Of course, since grand fir occurs over a wide geographical range in its native habitat with marked variations in temperature and precipitation and since consequently there are climatic races within the species (Müller, 1938), it would be possible to find a race adapted to drier conditions, but such a race would probably grow more slowly and thus have no advantage over native European conifers. The grand fir seen in Europe was all of the fast-growing coast form.

Grand fir planted in 1894 near Lausanne, Switzerland, has been dying steadily since 1945 because of shoestring root rot caused by the honey mushroom [*Armillaria mellea* (Vahl.) Quel.] so that in 1950 the indications were that the remaining trees would die in a few years. Basically the cause seemed to be drought since precipitation at this locality averages but 40 to 50 inches annually and, in addition, for the 7 to 8 years prior to 1950 there had been an annual precipitation deficit as high as 30 percent in some years. Severe attacks on conifers by *Armillaria mellea* following drought are characteristic.

Western red cedar

Western red cedar (*Thuja plicata* D. Don.) is little seen in continental Europe, probably because in Great Britain it has had so much difficulty in even getting a start that the tree was discredited quickly. The cedar leaf blight fungus (*Keithia thujina* Durand) came with the tree from North America, and the fungus finding the moist climate of Great Britain so much to its liking has reduced the cedar to a slow-growing tree at least during its younger stages.

Jack pine

In southern Sweden, a flourishing plantation of 12-year-old jack pine (*Pinus banksiana* Lam.) was ruined by a fungus (*Dasyscypha* sp.) which ordinarily occurs as a harmless saprophyte on the native Scots pine. The fungus caused flattened cankers on the main stem just above ground level. Many trees were completely girdled.

Caucasian fir

Caucasian fir [*Abies nordmanniana* (Steven) *Spach.*], introduced from the western spurs of the Caucasian Mountains largely as an ornamental, was followed by an aphid (*Adelges nüsslini* Börner). In the Caucasus the insect is not significantly damaging to its host, but in southern Germany under relatively drier climatic conditions the parasite has become so severe that Caucasian fir can no longer be grown there. However, that is of little consequence compared to the fact that the aphid is now attacking silver fir so severely that foresters fear that this fir, which is the principal species in the famous Black Forest, will have to be largely given up there, particularly on those sites below the natural lower altitudinal limit for the tree.

United States of America

In the United States, where because of the large number and variety of native species they are little needed, there has been little success with exotics, although so far they have been tried in a small way only. In Michigan, Scots pine was attacked by a gall rust (*Peridermium* sp.), Himalayan pine (*Pinus excelsa* Wall.) was so damaged by a canker with which *Valsa superficialis* Nitschke was associated that ultimate destruction of the plantation was certain, Japanese red pine (*P. densiflora* Sieb. and Zucc.) was considerably affected by dieback of the leaders and branches probably caused by *Cenangium abietis* (Pers.) Rehm, and Austrian pine was completely destroyed by sweetfern blister rust, *Cronartium comptoniae* Arth. (Baxter, 1937). Ornamental Austrian pines in the northeastern United States are so susceptible to dieback of the twigs caused by *Sphaeropsis ellisi* Sacc. also known as *Diplodia pinea* (Desm.) Kickx. (Waterman, 1939), that this factor alone, aside from other pests, probably makes the tree valueless for forest planting. Scots pine plantations in Pennsylvania grew vigorously for 20 years and then disintegrated quickly from various factors including attacks by fungi (Aughanbaugh, 1935). In New York State, Scots pine plantations have been extensively damaged by the spittle bug (*Aphrophora parallela* Say.) with practically all trees over 20 years old killed (McIntyre 1939). Elsewhere in the State this tree has been severely attacked by the Woodgate gall rust (York 1929).

Both Norway spruce, which has been planted frequently, and European larch (*Larix decidua* Mill.) have shown promise in the northeast (Hosley, 1936; Hunt, 1932), but these species have not been established

long enough for a conclusive test. Some plantations of spruce have been destroyed by the white pine weevil (*Pissodes strobi* Peck), a native insect on *Pinus strobus* L. Although eucalypt in California is sometimes cited as a successful exotic, this species never has fulfilled the purpose for which it was introduced, i.e., timber production, because of the unsatisfactory technical qualities of the rapidly grown wood. However, it has become invaluable for shade and ornamental purposes.

East Africa and Chile

Monterey cypress (*Cupressus macrocarpa* Gord.) in East Africa exemplifies two dangers to an exotic: (1) a native fungus of no consequence becoming pathogenic on an exotic, and (2) a fungus of no significance on the exotic in its native habitat causing loss to the tree in its new environment. *Monochaetia unicornis* (C. & E.) Sacc., found in a harmless form on a native juniper (*Juniperus procera* Hochst.), apparently has become pathogenic on various cypresses, including Monterey, causing severe cankers on young trees in plantations (Rudd Jones, 1952a). *Polystictus versicolor*, a wood-destroying fungus relatively world-wide in its distribution, but confined to dead trees in the native habitat of Monterey cypress in California, causes a serious white rot of the wood of living trees in East Africa (Rudd Jones 1952b).

Although exotic conifers have been planted to some extent in Chile, little is known about their development. Several needle cast fungi native to the northern hemisphere have been reported on exotic pines (Bernath, 1937).

Successful Results

The foregoing paragraphs present some of the unsatisfactory results with exotics, but there have also been successes. However, most exotics have not yet been established for a sufficiently long time to make a final judgement as to their ultimate value.

Europe

The best results with exotics in western Europe have been attained with Sitka spruce and Douglas fir in Denmark and Great Britain, both countries having few tree species. Scots pine (*Pinus sylvestris* L.), for example, is the only native commercial conifer in Great Britain.

The maritime climate of Great Britain, with its normally mild and moist growing season, is even more favorable to conifers from western Oregon, Washington, and British Columbia, than is the climate of their native habitat with long dry summers. Mild wet winters are the rule in both regions. However, it is significant that Douglas fir, regarded by British foresters generally as the most valuable exotic in the decade beginning in 1920, yielded its place to Sitka spruce during the next decade because of attacks by certain tree pests on Douglas fir and the somewhat unsatisfactory qualities of its coarse, rapidly grown wood. Difficulties with some Sitka spruce plantations, probably largely the result of their establishment on unsuitable sites, had by 1950 given rise to the idea that grand fir (*Abies grandis* Lind.) might be the best conifer for the future.

Red oak (*Quercus borealis* Michx.) has done well so far in Germany, growing on somewhat poorer soils than native oaks. Most of the stands are still young, the only old trees being individuals or small groups. In France there is a stand planted in 1929, which is now reproducing naturally (Pardé, 1937). Red oak is proving quite valuable in Belgium. Black locust (*Robinia pseudoacacia* L.) so far has been successful in Romania where about 70,000 acres have been planted (Venet, 1937). It is also said to be doing well in Hungary (Engel, 1938).

Japanese larch (*Larix leptolepis* Gord.) has done remarkably well in certain localities in southern Germany where the annual precipitation is sufficient for it. During the dry summer of 1934 the tree was severely damaged in other parts of Germany, so that its usefulness is restricted. As yet it is not known whether this species will reproduce naturally in Europe. A bark lesion caused by *Phomopsis pseudotsugae* Wilson within the past few years has been found at several localities to be prevalent on and damaging to Japanese larch, not by killing trees but by causing large scars on the lower portion of the bole that later reduce the quality of the wood. Infection occurs through wounds during the dormant period of the tree. Since the bark lesions commonly follow artificial pruning, infection can be largely prevented by pruning in May, June, and July when the trees are most active (Van Vloten, 1952).

The introduction of European larch (*Larix decidua* Mill.) into Great Britain from continental Europe has proven relatively successful despite the damage to many plantations by canker caused by *Dasyscypha willkommii* (Hart.) Rehm. On good sites the canker is of little consequence.

Australasia and South Africa

The outstanding success with exotics has been obtained in Australasia and South Africa, but sufficient time has not yet elapsed for a conclusive test. Monterey, ponderosa, Corsican and maritime pines (*Pinus radiata* D. Don., *P. ponderosa* Laws., *P. laricio* Poir., and *P. pinaster* Sol.) have been the species most widely planted in Australia. Along the east coast in the summer rainfall area, loblolly, longleaf and slash pines (*P. taeda* L., *P. palustris* Mill., and *P. elliottii*. Engelm.) are most promising. Loblolly pine in particular is doing extremely well. Monterey pine, Douglas fir, Corsican, ponderosa and maritime pines have been most used in New Zealand; and Monterey, maritime and spreading-leaved pines (*P. patula* Schlech. and Cham.) in South Africa, the last-named tree coming from Mexico. The species enumerated have been arranged roughly in the order of their importance in each country. The growth of all has been superb and of Monterey pine phenomenal, saw timber commonly being produced in 25 years.

Fortunately, all these trees are native to the North Temperate Zone where the seasons are diametrically opposite to those in the Southern Hemisphere. Consequently, it has been practically impossible to introduce these species as living plants, which, together with a considerable degree of caution against such practice, has resulted in the exclusion of the pathogens occurring on these trees in their native habitat. Monterey pine, in particular, is affected by a number of fungi and insects in its California home. Monterey and spreading-leaved pines possess an additional advantage in that they are relatively homogeneous species, so that the vexing problem of the most suitable strains or races within the species does not obtrude itself as it does in such variable species as maritime, Corsican and ponderosa pines, and Douglas fir. Although such extensive planting of pure stands is extremely risky, less financial risk is involved than in most artificially created pure stands because of the short rotation in Australasia and South Africa. Serious as a killing epidemic would be, still the loss would be much smaller than would result from the same damage to stands on a 50-year or higher rotation.

However, conifers introduced from the Northern into the Southern Hemisphere have not remained entirely free from insect pests or pathogens. A wood wasp (*Sirex noctilio* F.), native to Europe, has been established in New Zealand for at least 50 years where it is attacking Monterey pine and other exotic conifers (Miller and Clark, 1935; Hanson 1939, page 52). The insect usually infests suppressed, dying and dead

trees, but it is damaging because it hastens the death of trees that could be utilized. It also creates conditions favorable to the breeding of a European bark beetle (*Hylastes ater* Payk.) that is also established in New Zealand; this beetle is particularly injurious to pine seedlings. Not until the wood wasp has reached its possible range distribution so that the population density can increase rapidly will the complete extent of the damage this insect is capable of causing be realized. Although as yet unknown on exotic pines in Australia, living Sirex wood wasps in all stages of development were intercepted at several Australian ports during 1951 in nine cargoes of timber, mostly spruce and fir, originating from European ports (Anonymous, 1952, page 25).

Conclusions

From the foregoing it can be concluded that the vicissitudes to which an exotic is likely to be subjected will at least increase the difficulty and cost of establishing the species in a new habitat, even if establishment is not precluded entirely. One should make sure that the introduced tree has some essential advantage over the native species and gives promise of some possibility of successful culture, and then proceed on a properly planned, long-time experimental planting program. Early promise must not be accepted as a guarantee for the future to be followed by extensive planting, because this way lies the possibility of unreasonable losses. Not until the end of the first rotation can a reasonable prediction be made as to the success of an exotic; even this is not conclusive for all time. It is important that all the races in a variable species have the same long-time test, because from the biotic standpoint, varietal or racial differences within a variable species can be greater than differences between species. Exotics are not all foredoomed to failure, but for every exotic the chance of failure is much greater than the chance of success.

Extension of the Range of Native Trees

Although extension of the range of a native species has more chance of success, the same considerations apply to them as to exotics. So-called indigenous trees can be just as truly exotics if they are carried too far outside their natural range within their own country than as if they came from another continent. A tree species at the limits of its natural range commonly responds to even small extensions of its locality by a weakened constitution, thereby becoming more susceptible to disease. Small altitudinal movements are likely to be as important as great horizontal (latitudinal) ones. However, there should be less difficulty in extending the range of native species than in introducing exotics. The native tree is a known species the characteristics of which in its natural habitat are well understood or can be determined with reasonable promptitude, so that any variations from the normal in its new habitat can readily be detected. With an exotic this is more difficult to do.

Europe

In Europe the ranges of native conifers, particularly Norway spruce, Scots pine and European larch, have been widely extended with most instructive results.

Norway spruce

Norway spruce (*Picea abies* Karst.) is a tree of the far north or of the mountains. Its range has been greatly extended, particularly from the mountains into the lowlands, well demonstrated in Saxony and Silesia. Although most stands there were quite gratifying during the first rotation, there has often been a marked to disastrous reduction in increment during the second and third rotations, the stands being damaged by various insects and fungi, particularly by *Fomes annosus* (Fr.) Cke. causing root and butt rot. While it is always controversial as to whether the fundamental cause of such stand deterioration has been an unsuitable site, wrong seed provenance or pure stands instead

of mixed, yet where Norway spruce was seen in its native habitat on good sites, naturally reproduced and in normal mixture, it was vigorous and practically disease free.

Scots pine

The range of Scots pine (*Pinus sylvestris* L.) has also been greatly extended, but in many instances the early promise of the tree has not been fulfilled. As a specific example, in the Forest of Rouvray a few miles south of Rouen in Normandy, Scots pine was introduced more than 100 years ago and now occupies about 6,000 acres in pure stands (Rodger 1939). The stands were satisfactory for a long time but during later years deterioration has begun. The trees are dying back, which is attributed partly to butt and root rots caused by *Fomes annosus* and *Armillaria mellea* (Vahl.) Quel. and partly to sulphur dioxide in factory smoke from the Seine Valley. The two fungi are secondary because they only injure trees first weakened by some other factor. In addition, defoliating insects and bark beetles have contributed to the damage. Remedial measures undertaken so that Scots pine can be perpetuated are an admixture of hardwoods, heavier and more frequent thinning, removal of diseased trees and stumps, and adequate fire protection.

European larch

European larch (*Larix decidua* Mill.) is native to the mountains of south central Europe, but its range has been so extended that it is now distributed over the entire continent. Outside its native habitat, although some stands have flourished, the tree has been plagued especially by canker and dieback caused by frost assisted by *Dasyscypha willkommii* (Hart.) Rehm (Münch 1936), often to the extent of plantations becoming worthless. Two races of the tree are recognized; namely, the Tyrolean, native to the Alps, and the Sudeten, native to the mountains along the border between Silesia and Moravia. Although canker does occur on Tyrolean larch in its native habitat, actual damage is rare, whereas canker is practically unknown where Sudeten larch is native. Apparently, the Sudeten race is adapted to most of Germany so that it can be grown safely, but the Tyrolean race is severely affected by canker and dieback. However, when the Sudeten larch is moved farther from its native home to where conditions are less suitable, it also becomes susceptible. In Sweden, it is just as subject to cankering as the Tyrolean race.

The Sudeten race was examined in the Forest of Landskron in Moravia about 100 miles east of Prague where the tree is native in the mountains, growing in mixture with Norway spruce, silver fir, Scots pine and beech. The larch was superb. Not a single canker was found despite a careful search. The forester in charge said he had never seen a cankered larch in the forest, although he was quite familiar with the disease from previous experience in southern Germany. Just 30 miles to the north, at a lower elevation on the flat terrain of Upper Silesia, this same race was introduced many years ago where it has since been growing splendidly and reproducing naturally in mixture with Norway spruce, Scots pine and some silver fir. On the main stem of an occasional sapling a canker could be found which was being overgrown without damage to the tree. The cankers had no economic significance but they were a warning that the tree was not on a completely satisfactory site.

Silver fir

Silver fir (*Abies alba* Mill.) in western Europe is threatened by an introduced aphid (*Adelges nüsslini* Börner) which presumably came from the Caucasian Mountains on *Abies nordmanniana* (Steven) Spach. The damage in Germany is worst where silver fir is being grown outside of its natural habitat, but damaging infestation seems to be moving steadily higher to elevations where the tree is native.

United States of America

In the United States, extending the natural range of native trees is just getting under way, although it began decades ago on a small scale with certain species. Ponderosa pine (*Pinus ponderosa* Laws.) occurred frequently enough in the east by 1868, so that it was recorded as one of the common plants (Gray, 1868, page 311). Ponderosa pine in the eastern United States is so far from its native habitat that it should be regarded as exotic in character rather than as a native tree with its range extended. This tree, actually never seriously considered for forest planting in the east, offers little promise because it is relatively slow-growing; but even if it was quite satisfactory, its usefulness would be extremely limited because of sweetfern blister rust fungus (*Cronartium comptoniae* Arth.) which has destroyed nursery stock and young plantations in the Lake States. Lodgepole pine (*Pinus contorta* Loud.) has also suffered to the same degree. Sweetfern [*Comptonia peregrina* (L.) Coult.], necessary for the perpetuation of the rust fungus

is common enough in the East so that extensive areas, otherwise satisfactory, cannot be used for planting pine species susceptible to the rust.

Two species, the ranges of which are now being considerably extended, are slash pine (*Pinus elliottii* Engelm.) and red pine (*P. resinosa* Sol.). Slash pine is being brought north from its home along the Gulf Coast, whereas red pine is being moved south from its natural habitat in the northern part of the Lake States and New England. The slash pine plantations are only a few years old as yet and so far no limiting biotic factor has appeared.

Plantations of red pine in eastern Pennsylvania, outside its natural range, have failed because of root rot caused by the fungus *Phytophthora cinnamoni* Rands (Ibberson, 1949). This root rot has not been observed where the tree occurs naturally. In southern Michigan, in southern Connecticut and elsewhere, there have been outbreaks of Tympanis canker in plantations (Hansbrough, 1936; Baxter, 1937, page 31). Although the causal fungus (*Tympanis confusa* Nyl.) is present within the natural range of red pine, it does not cause cankers there. The attack on red pine south of its natural limits is merely a warning that the environment is becoming less satisfactory.

More serious is the attack by the European shoot moth (*Rhyaconia buoliana* Schiff.) on plantations of red pine in southern New England (Friend and West, 1933). This insect, introduced from Europe about 1914, has not been found where the host tree is native but the damage to plantations has been severe enough to make them economically worthless. In addition, several native and introduced sawflies, including the native *Neodiprion lecontei* Fitch and the European *N. sertifer* (Geoff.), have been damaging. Matsucoccus scale, recently discovered but not yet identified exactly and of unknown origin, seems so potentially destructive that it may be the worst of all. None of these insects are of consequence within the natural range of red pine but their attacks have been so severe on trees established outside the natural range, particularly to the south, that in the northeastern states planting of red pine southward has been practically given up.

Critical Climatic Conditions

Species planted outside their natural habitat may flourish for years but they are particularly vulnerable to critical climatic conditions. In the United States beginning in 1903, jack pine (*Pinus banksiana* Lam.) from the Lake States was planted in the sand hill region of Nebraska. For some years this species seemed satisfactory for planting in that

normally dry, severe climate, but subnormal precipitation beginning in 1930 and extending through 1939 severely damaged plantations of all ages, old as well as young. Old plantations of ponderosa pine and eastern red cedar (*Juniperus virginiana* L.), both native, withstood the protracted drought relatively well. In this instance about 30 years elapsed before the tree outside of its natural environment encountered conditions which it could not withstand.

During recent years, various parts of Europe have suffered from drought. The dry years from 1946 to 1950 inclusive, particularly 1947, were extremely destructive to Norway spruce (*Picea abies* Karst.) in Bavaria (Woelfle 1949, 1950, 1951). Spruce in pure stands valued at several million marks was killed by bark beetles, largely *Ips typographus* L. and *Pityogenes chalcographus* L., and by root fungi, mostly *Armillaria mellea* and to a lesser degree *Fomes annosus*, which attacked the trees weakened by drought. Typical was a 100-year-old stand in northern Bavaria examined in the spring of 1950. Nearly half the stand had been removed already and trees were still dying. The species which occurred naturally in the locality were little affected.

The forest of Vallombrosa in Italy was originally composed of beech (*Fagus sylvatica* L.) and at higher elevations silver fir (*Abies alba* Mill.) with oak, mostly *Quercus cerris* L., as an understory. Chestnut (*Castanea sativa* Mill.) occupied the lower levels. However, this mixed stand was converted to pure silver fir and, in addition, the fir was established below its lower altitudinal limit. Following the severe drought of 1944-45 the weakened trees were killed by root rots caused principally by *Armillaria mellea* but to some extent by *Fomes annosus* (Biraghi 1949). Where the trees were not affected by drought, neither fungus was of any consequence. Drought injury was most severe to firs below their natural altitudinal limit. A similar difficulty occurred in 1923 (Petri, 1923).

Provenance of Seed

Both for native trees outside their natural range and for exotics, the provenance of seed is extremely important. Neither an excellent site nor excellent care can produce a satisfactory stand from seed of a poor provenance. Long experience with trees outside their natural habitat leads to the drastic conclusion that it is better not to establish a plantation at all than establish it without knowing the source of the seed. Again and again, when the crucial point regarding a plantation is the provenance of the seed, this information is not available.

In Germany, in several forests, excellent stands of larch (*Larix decidua* Mill.) have been seen and it would have been profitable to increase the larch stands there, but the seed source was unknown and only when the plantations attained sufficient size to produce seed in quantity could new satisfactory plantations be established. If the seed provenance had been known, increase of the larch stands would have been simple. The same circumstance has occurred with other species.

The frequent deterioration of larch in western Europe can often be traced to seed of unsuitable provenance. Specifically, in a forest in northwest Germany, trees descended from larches raised from Sudetic seed are of rapid growth, fine form, and free from canker; whereas others, probably of Alpine origin, are nearly all crooked and severely cankered (Gernlein, 1948).

Unfortunately, it is easier to collect seed from short shrubby trees than from tall well-formed ones, and it is the former that are undesirable parents. The characteristics of an undesirable race are often so prominent that it is relatively simple to determine the provenance of the seed by the appearance of a plantation. In Scotland, there were two plantations of lodgepole pine (*Pinus contorta* Loud.) side by side on the same site, planted at the same time, grown in the same nursery, but from two lots of seed of unknown provenance. In one plantation the trees were fast-growing and of excellent form, such as are found on the better sites in the Rocky Mountains; those in the other plantation

were slow-growing, shrub-like and twisted, exactly like the shore form of lodgepole pine which is found just back of the beaches along the Pacific Ocean. In addition, the trees in the poor plantation were attacked by a needle fungus. The poor form of Scots pines (*P. sylvestris*) in some plantations in the United States is, like the Darmstadt race of Scots pine in Germany, characterized by crooked boles. Japanese red pine (*P. densiflora* Sieb. and Zucc.) planted in Michigan formed many leaders and had twisted boles (Baxter, 1937, page 31).

Artificial Spread of Pathogens

THE spread of pathogens over great distances is almost invariably brought about by man, and as methods of transportation increase in number and in speed, the chances of spreading pathogens likewise increase.

Carriers of Pathogens

Experience has shown that the exchange of living plant material is extremely hazardous. The chestnut blight fungus, which came to the United States from Asia on nursery stock, has proven so uncontrollable that one of the most valuable hardwoods will be commercially extinct before long unless resistant trees can be developed by cross-breeding or selection. Even if successful, it will probably be impossible to restore chestnut to more than a small portion of the forest land it once occupied. The loss of American chestnut [*Castanea dentata* (Marsh.) Borkh.] is the outstanding example in forests of the world of the loss that can be caused by an introduced pathogen, and it is an appalling lesson on the danger of introducing nursery stock from other countries. Europe now faces the same future with its valuable native chestnut (*C. sativa* Mill.).

The white pine blister rust fungus was introduced into the United States and Canada on seedlings from German and French nurseries. Although controllable by eradication of *Ribes*, this constitutes a perpetual addition to the cost of growing white or five-needle pines in North America.

The brown-tail moth [*Nygmia phaerrhoea* (Donov.)], a destructive defoliator of various broadleaf trees, was introduced from Europe to the United States on nursery stock. The insect was discovered in 1897. The insect is permanently established, and in areas where severe infestation continues year after year has to be controlled by expensive spraying with DDT.

Although not proven, it seems likely that the fungus-causing Rhabdocline needle blight of Douglas fir was first introduced into Scotland

on forest-dug seedlings from North America, then spread over Great Britain by shipments of nursery stock and by wind-borne spores; afterwards, it was carried from Great Britain to Germany on nursery stock, and from Germany spread over much of western Europe on nursery stock and also naturally. The fungus responsible for Adelopus needle blight of Douglas fir probably has followed much the same pattern. Both these pathogens have also been introduced into the eastern United States from their native habitat in the west, presumably on living plants, since the distance seems much too great for wind-borne rather thin-walled spores to travel and remain viable.

In addition to the above, other pathogens probably carried on living plants into Europe include the Douglas fir aphid (*Chermes cooleyi* Gill.), the silver fir aphid (*Adelges nüsslini* Börner), the cedar needle blight fungus (*Keithia thujina* Durand), and the chestnut blight fungus [*Endothia parasitica* (Murr.) A. & A.]. The persimmon wilt fungus (*Cephalosporium diospyri* Crandall), the mimosa wilt fungus [*Fusarium perniciosum* f. *oxysporum* (Hepting) Toole], and several insects probably have been introduced on living plants into the United States

Cuttings, although not quite as dangerous carriers as complete living plants, are also hazardous There is no way to completely sterilize plants or cuttings without severe injury or death to the tissues. With the large amount of poplar breeding and selection that is now underway in Europe, South America and to a lesser degree in the United States, which has resulted in a considerable interchange of poplar cuttings between some countries, there is a great danger that destructive poplar diseases may be widely distributed Recent attempts to sterilize poplar cuttings carrying the organisms causing leaf blotch (*Septotinia populiperda* Waterman and Cash), Septoria canker (*Septoria musiva* Pk.) and Dothichiza canker (*Dothichiza populea* Sacc. and Br.) have not been successful (Waterman and Aldrich, 1952).

However, it is not by means of living plants only that pathogens can be spread. Even dried plants can be dangerous. A needle rust of Scots pine (*Pinus sylvestris* L.) came into Wisconsin on leaves of sow thistle (*Sonchus asper* (L.) Hill) in an importation of Norway spruce (*Picea abies* Karst.) from Europe (Davis, 1913). The rust (*Coleosporium sonchi-arvensis* (Pers.) Lev.) spread to living sow thistle plants and then to planted Scots pines in the immediate vicinity. Fortunately, this needle rust proved of no consequence but the manner of its introduction is important.

Pathogens can be carried in soil, so that the movement of living plants is doubly dangerous; a pathogen may be in the plant or in the soil attached to the roots. A nursery in New Hampshire was free from damping-off for many years until transplants were brought in from another nursery. Almost immediately a destructive damping-off fungus appeared. Since the introduced trees were too old to be affected by damping-off, the fungus was evidently in fragments of soil attached to the roots. The movement of plants from nurseries is particularly likely to result in the spread of soil-inhabiting fungi causing root rots (Zentmyer, Baker, and Thorn, 1952). It is more difficult to detect diseased roots by inspection than diseases of the aerial portions of plants.

The introduction of soil from another nursery to promote the development of mycorrhiza can result in soil contamination. There had been no damping-off caused by *Cylindrocladium scoparium* Morg. at a nursery in New Jersey until soil was brought from another nursery. From that moment onwards the prevalent fungus causing damping-off was *C. scoparium.*

The elm disease fungus [*Ceratostomella ulmi* (Schwarz) Buisman] was introduced into Europe from Asia (presumably its native home) during the first world war probably on basket or crating material; into the United States from Europe on burl logs for furniture veneer manufacture; and into Canada from Europe probably on crating material. Sirex wood wasps have recently been intercepted at Australian ports in timber shipped from Europe.

The gypsy moth [*Porthetria dispae* (L.)], so destructive to broadleaf trees, first appeared in the United States in 1869 when insects escaped that had been brought from Europe for experimental purposes. Although since that time more than one hundred million dollars has been spent to keep the insect under control, the estimated average annual damage resulting from defoliation with the consequent loss of growth and death of trees still amounts to one and one-half million dollars in the United States.

Although the means by which pathogens can be introduced are so many — for example, insects in the egg stage can be carried on almost anything — there is no definite evidence that any pathogen of consequence to trees, particularly to conifers, has been distributed by seeds. Furthermore, coniferous seeds can be sterilized quite effectively by means of certain chemicals, but some seeds of broadleaf trees are not easily treated.

There are pathogens now known and undoubtedly many more unrecognized that could be extremely destructive if introduced to other parts of the world. Because so much work to increase poplar production is now underway, particularly in Europeand to a lesser degree in North and South America, the possibilities of introducing pathogens destructive to poplars are great indeed, since there is a widespread exchange of cuttings from country to country and even from continent to continent (Gravatt, 1952).

The worst pathogen on poplar, in the experience of the writer, is *Pseudomonas syringae* f. sp. *populea* (Sabet and Dowson, 1952), also known as *P. rimaefaciens* Koning, causing bacterial canker (Koning, 1938). Although this bacterium is not yet known except in Europe, it has severely attacked certain North American poplars planted there. Another pathogen native to Europe but which has long since been introduced into the United States and Canada is the fungus *Dothichiza populea* Sacc. and Br. causing canker (Goidanich, 1940). In the United States and Canada it has been damaging in nurseries and plantations but has not yet appeared in natural stands. There are two poplar diseases recently noticed in Europe the causes of which are unknown (Gravatt, 1952, page 24). The fungus *Septotinia populiperda*, causing a leaf blotch of poplars, although first found in Europe, is also present in the United States (Waterman and Cash, 1950).

There are two extremely dangerous fungus pathogens of poplar in the United States and Canada. The first of these is *Septoria musiva* Pk., which causes a leaf spot of little consequence on native species but produces such severe cankers on native and exotic hybrid poplars that entire plantations are completely destroyed. The other is *Hypoxylon pruinatum* (Klotsche) Cke. on aspens (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) causing a canker. A mortality of 70 percent has been reported in some stands. Considering the value of aspen (*P. tremula* L.) in northern Europe, if *H. pruinatum* was introduced it could be catastrophic.

There are pathogens attacking poplar foliage that can be damaging, for example, *Septotinia populiperda* mentioned previously. Melampsora rusts, although world-wide in distribution, are composed of various species, strains, and hybrids which differ according to region. Some poplars are so susceptible to these rusts that they cannot be used for planting. *Taphrina aurea* (Pers.) Fr., causing yellow leaf blister, although widespread, also varies greatly in its virulence.

Pathogens on Willows, Ashes and Oaks

The bacterium, *Bacterium salicis* Day, which causes watermark disease of willow, actually a destructive dieback, is known so far from Europe only. It is so damaging to willows in Great Britain that it seems reasonable to suppose that, if the pathogen was distributed elsewhere in the world, it would be as bad or even worse. Another bacterium, *B. savastanoi fraxini* Tub., causes a cankerous gall on European ash (*Fraxinus excelsior* L.). Although the pathogen is known only in Europe, it is potentially dangerous to the United States and Canada because white ash (*F. americana* L.) native to those countries is susceptible as demonstrated by artificial inoculations.

Oaks are the most valuable broadleaf species in the North Temperate Zone. At present, a fungus, *Endoconidiophora fagacearum* Bretz, better known by the name of its imperfect stage, *Chalara quercina* Henry, is causing a wilt that is killing oaks over an extensive area in the United States and is spreading rapidly (Fowler, 1953). The origin of the fungus is unknown, but since nothing similar has been reported elsewhere, it must be concluded that this fungus is a threat to oaks in other parts of the world.

Pathogens in New Habitats

Powdery mildew of oak caused by *Microsphaera alphitoides* Grif. and Maubl., almost certainly introduced from North America where it is native and not damaging, has been extremely injurious to indigenous oaks in Europe for nearly 50 years. In the French Basque region the fungus has caused almost total destruction of native *Quercus toza* Gill. and Bosc. (Parrot, 1948). This will have to be replaced by red oak (*Q. borealis*) and pin oak (*Q. palustris* Muench.) both from North America and resistant to powdery mildew. The fungus is potentially dangerous to oaks elsewhere in the world. Since overwintering is by means of fructifications on dead leaves and mycelium in buds it can be easily distributed.

Plantations are more susceptible to pathogens causing root rot than are naturally reproduced stands. Such pathogens can be carried long distances either in plant tissue or in soil. There are two fungi known to cause root rot that are particularly dangerous because of the great variety of hosts that they attack. *Helicobasidium mompa* Tanaka which occurs in Japan is known to attack 104 species of plants, includ-

ing broadleaf trees and conifers (Ito, 1949). The soil-inhabiting fungus *Phymatotrichum omnivorum* (Shear) Duggar, which so far is confined to the southwestern United States, causes a destructive root rot of both broadleaf trees and conifers. Although this fungus is apparently limited in its distribution by high temperature requirements, undoubtedly, there are various places in the world where it might flourish —for example, in southern Europe near the Mediterranean.

The blister rust fungus *Cronartium ribicola* Fischer has largely stopped the planting of exotic five-needle pines throughout Europe and has added considerably to the cost of growing five-needle pines in North America where they are native and valuable commercially, because the removal of *Ribes*, the alternate host of the fungus, is essential to the production of a satisfactory stand. There are other fungi causing blister rusts that seem potentially capable of great damage outside their native habitat. In the Himalayas, *Cronartium himalayense* Bagchee occurs on long-leaved Indian pine (*Pinus roxburghii* Sarg.), the alternate host being species of *Swertia* (Spaulding, 1952). Since *Swertia* is found in Europe and North America, this fungus if introduced might be serious on hard pines there. In Europe, *Cronartium asclepiadeum* (Willd.) Fr., also known as *Peridermium pini* (Willd.) Kleb., causes resin top of Scots pine resulting in the deformation and death of many trees. This rust fungus is specially dangerous since no alternate host is needed, infection can occur directly from pine to pine. The reaction of other hard pines to it is unknown. Probably the most dangerous of all is *Cronartium harknessii* (Moore) Meinecke common on ponderosa pine (*Pinus ponderosa* Laws.) and lodgepole pine (*P. contorta* Loud.) in the western United States and Canada, causing large globose galls on the trunks and branches. The fungus has found its way to the eastern United States and Canada, where, under the name of the Woodgate gall rust, it has vigorously attacked Scots pine of all ages. Trees are killed or deformed, as many as 18,000 galls having been found on a single tree. If this rust fungus was introduced into Europe, losses would be terrific and the pathogen would be extremely difficult to control because infection occurs directly from pine to pine. Of course some trees are resistant to it, but it would require decades to build up resistant stock. Meanwhile, Scots pine stands would be decimated.

The rust fungus *Melampsora pinitorqua* Rostr. causes twisted shoots of Scots pine in Europe but is unknown elsewhere. However, the alternate stage of this rust is on poplars which occur wherever hard pines grow.

Seemingly, the most dangerous insect if introduced elsewhere would be the nun moth (*Lymantria monacha* L.) which periodically causes heavy defoliation of conifers, particularly Norway spruce (*Picea abies* Karst.) and Scots pine, and to a lesser degree defoliates broadleaf trees. If introduced into the United States, for example, this insect might be as bad on conifers as the gypsy and brown-tail moths are on broadleaf trees.

The foregoing pathogens are those that are well-known in their native habitats and potentially dangerous to trees elsewhere in the world. Actually, there are undoubtedly many more obscure or even unknown pathogens that would be capable of causing great damage in new habitats and on tree species unaccustomed to them.

Prevention of Disease

Diseases should be prevented from becoming serious in plantations rather than controlled after they have become sufficiently severe to cause heavy losses.

The most effective prevention of diseases is to establish plantations only on sites to which species are well adapted. Consequently, it is best to use native species for reforestation because it is relatively simple to select the proper site for them. This is more difficult with exotic species for which site selection must be largely by trial and error, since it is rarely possible to make a sufficiently detailed evaluation of an exotic in its natural habitat so that an exactly equivalent habitat can be selected elsewhere.

Spacing

An important factor in establishing a plantation is spacing. The usual spacing, if no definite distance has previously been established, is 6×6 feet. A narrower spacing such as 5×5 feet may be advisable for tolerant species, whereas a wider spacing, up to 8×8 feet, may be used for intolerant trees. Wider spacing reduces planting costs and delays the first thinning, but it may necessitate earlier and more frequent pruning. There can be a definite relation between spacing and the activities of pathogens. In the northeastern United States, eastern white pine (*Pinus strobus* L.) could be planted 8×8 feet except for the weevil, *Pissodes strobi* (Peck). Because of this insect, spacing 5×5 feet is necessary so that enough trees free from forks and crooks will remain to form a crop. The best method is to mix white pine with a non-susceptible species. Spacing of red pine (*Pinus resinosa* Sol.) 8×8 feet reduces the incidence of Tympanis canker caused by *Tympanis confusa* Nyl., as compared to spacing 6×6 feet or less. Death from root rot caused by *Fomes annosus* (Fr.) Cke. has occurred in some coniferous plantations following thinning. Investigation is needed to decide whether closer or wider spacing might prevent this, in the first instance by providing more trees per acre to form the final crop, and in the second instance by making it possible to delay thinning until after the trees are older and more resistant to the pathogen.

Weeding, Thinning and Pruning

Once a plantation is established it must be properly cared for by weeding, thinning, and pruning to keep it vigorous and productive of high quality wood. A neglected plantation rarely justifies the investment in it. Furthermore, these operations can affect disease. In broadleaf forests of the northeastern United States, stems severed during weeding must not be left in contact with stems of living trees because cankering and death may result from attack by the fungus *Hymenochaete agglutinans* Ellis. Tympanis canker of red pine has been induced by stagnation of unthinned plantations in Michigan and New York (Hansbrough, 1936, pages 11 and [38). Broadleaf trees are best thinned when the leaves are off so that it is easy to see abnormalities on the stems. Pruning of Japanese larch (*Larix leptolepis* Gord.) in Holland can be done safely during spring and summer when the host is active, whereas pruning during the dormant period results in stem lesions caused by *Phomopsis pseudotsugae* Wilson (Van Vloten, 1952).

Introduction of Exotics

Mixed plantations should be established rather than pure, unless a species grows naturally in monoculture. Pure stands are more susceptible to disease than mixed stands, pure even-aged stands being most susceptible of all.

Although exotics should be introduced only if they fulfill some definite need not met by a native species, there are parts of the world where exotics, particularly conifers, are needed. However, exotics should be used with the full realization that they are more liable to disease than native species and that their silviculture is unknown in the new habitat.

Living exotics or any parts thereof including cuttings should not be introduced, except under conditions where no part of the original plant is allowed to leave an insect- and fungus-proof detention house. This means exclusion of forest tree nursery stock and cuttings. Experience has shown that the introduction of living plants is extremely dangerous. Rigorous inspection of nursery stock and cuttings is not a sufficient safeguard because some pathogens have a long incubation period before the first symptoms appear. For example, the first symptoms, recognizable only by an expert, of the gall rust fungus *Cronartium harknessii* (Moore) Meinecke, which has been so damaging to

Scots pine (*Pinus sylvestris* L.) in the eastern United States and Canada, are not evident until a year after inoculation and in some instances more than two years.

Quarantines against diseased trees are inadequate because inspection by experts cannot intercept trees infected with a pathogen that has a long incubation period. Even a quarantine that prevents the entry of all trees of a species must be considered a measure of delay rather than a measure of exclusion because of the present rapid and varied means of transport. Nevertheless, quarantines are more important to forestry than to agriculture, since delay itself is more important because it requires 25 to 100 years or more to raise a crop of trees. Consequently, it is not possible to change species, to change cultural methods or to shift localities quickly in order to deal with a disease in forest trees as can be done with crops produced yearly.

The introduction of exotics should be by seeds entirely, because so far no forest tree pathogen of consequence is known definitely to have been introduced on seeds and furthermore most seeds can be disinfected by chemical treatment. It is extremely important that the provenance of all seeds used in forest planting be known exactly. Therefore, seeds must be obtained only from a reliable source of supply.

Nurseries should be kept sanitary and the stock carefully watched for indications of disease. Soil should not be brought into a nursery except from a natural stand or an old plantation of the species growing in the nursery within a distance not to exceed about 100 miles. Nurseries should be so located that the surrounding vegetation has no pathogens that will infest the nursery stock and be distributed to planting areas. A nursery for growing silver fir (*Abies alba* Mill.) surrounded by a dense growth of ferns was once seen in Scotland. The ferns were infested with the alternate stage of a needle rust which became so severe on the fir that the nursery was moved. Nursery stock should be examined for disease before it is planted out.

Selection and Breeding

If a pathogen is established and cannot be controlled by other means, the development of new resistant races or hybrids can be undertaken (Clapper, 1952). Since the resistance of natural forests to native pathogens is based on their mixed population, disease resistance must not depend on a single clone, a single selection, or a single hybrid. For safety, several must be developed. Selection and breeding as a means of disease control have their limitations. First, they are time-

consuming. Selection and breeding of chestnuts to obtain a desirable tree resistant to chestnut blight caused by *Endothia parasitica* (Murr.) A. & A. began in the United States in 1909. As yet, success is not assured. If and when blight-resistant chestnut is found that will be a satisfactory replacement for American chestnut [*Castanea dentata* (Marsh.) Borkh.], it will be possible to place it on only a portion of the area once occupied by American chestnut which has already lost its position in its native habitat. Second, even though a selection or hybrid is developed that is resistant to one pathogen, it may be susceptible to another. When the elm "Christine Buisman", a selection resistant to *Ceratostomella ulmi* (Schwarz) Buisman causing the elm disease, was finally distributed commercially, its usefulness in Holland and adjacent territory was soon destroyed by *Nectria cinnabarina* (Tode) Fr., a fungus usually saprophytic or weakly pathogenic on broadleaf trees in general, including elms.

Forest Protection Organization

In order to cope with diseases it is essential that any country engaged in forest production, and particularly a country in which large-scale forest planting is practiced, should have a forest protection organization staffed by experts. This organization should be responsible for the detection of pathogens and for their control. It is particularly important that nurseries and plantations be watched closely. When a pathogen appears, information regarding it should be disseminated quickly within the country in which it is found. Furthermore, complete information on the pathogen should be furnished to the forest protection organizations or qualified individuals in other countries so that they can be warned of the potential danger and be prepared to deal with it. Unless a disease is detected promptly and dealt with rapidly, it becomes difficult and in some cases impossible to control. Finally, it must be emphasized that research on forest pathogens is basic to prevention and control.

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